RISK-BASED COST OVERRUN PREDICTION MODEL FOR PETROCHEMICAL PROJECTS

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RISK-BASED COST OVERRUN PREDICTION MODEL FOR PETROCHEMICAL PROJECTS

by

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LIST OF ABBREVIATIONS

ANN	Artificial Neural Network
BN	Bayesian Network
BNN	Bayesian Neural Network
CART	Classification And Regression Tree
CCPS	Cross Conformal Predictive System
CP	Conformal Prediction
CPD	Conformal Predictive Distribution
CPS	Conformal Predictive System
CPS	Cross Venn-Abers Predictors
CV	Cross Validation
CVAP	Cross Venn-Abers Predictors
DL	Deep Learning
DP	Dempster-Hill Predictive Distribution
DT	Decision Tree
F1 Score	Harmonic Precision-Recall Mean
FNR	Proportion of actual positives predicted as negatives
FPR	Proportion of actual negatives predicted as positives
IVAP	Inductive Venn-Abers Predictors
KNN	K-Nearest Neighbors
KRRPM	Kernel Ridge Regression Prediction Machine
LR	Logistic Regression
LSPM	Least Squared Prediction Machine
NB	Naïve Bayes
NIOC	National Iranian Oil Company
NIPC	National Iranian Petrochemical Company
PCA	Principal Component Analysis
ROC	Received Operating Characteristic
RPD	Randomized Predictive Distribution
RPS	Randomized Predictive System
RRPM	Ridge Regression Prediction Machine
SVM	Support Vector Machines

TNR Proportion of actual negatives that are correctly predicted

TPR Proportion of actual positives that are correctly predicted

LIST OF APPENDICES

MODEL RAMALAN LEBIHAN KOS BERASASKAN RISIKO UNTUK PROJEK PETROKIMIA

ABSTRAK

Lebihan kos adalah isu yang ketara dalam industri pembinaan, terutamanya dalam projek petrokimia. Memahami sebab-sebab kritikal di sebalik lebihan kos dan kesannya adalah mencabar. Walaupun banyak kajian telah meneroka lebihan kos dalam pembinaan, memberi tumpuan kepada sebab dan implikasinya, terdapat kekurangan kajian yang khusus menumpukan pada mengenal pasti punca-punca ini dalam projek petrokimia. Selain itu, terdapat keperluan untuk model ramalan yang boleh menganggarkan kemungkinan berlakunya lebihan kos dalam projek-projek ini. Kajian ini bertujuan untuk menangani jurang ini dengan mengenal pasti faktor-faktor yang menyebabkan lebihan kos dalam projek petrokimia di Iran dan membangunkan model untuk meramalkan tahap lebihan kos. Kajian ini menggunakan kaedah penyelidikan kuantitatif (berdasarkan angka) dan kualitatif (berdasarkan pemerhatian) untuk menyelidik secara menyeluruh faktor-faktor yang mempengaruhi lebihan kos dan membangunkan model ramalan bagi keparahan lebihan kos dalam projek petrokimia di Iran. Data dikumpulkan melalui temu bual dan tinjauan. Tinjauan ini direka berdasarkan penemuan daripada ulasan literatur dan temu bual awal, yang membawa kepada pengenalpastian 30 faktor risiko. Data dikumpulkan daripada 99 peserta melalui tinjauan yang menilai hubungan sebab-akibat faktor risiko terhadap lebihan kos dalam projek petrokimia di Iran. Kajian ini menganalisis data yang dikumpulkan menggunakan pelbagai kaedah kuantitatif, termasuk Analisis Indeks Kepentingan Risiko. Ini membantu memprioritaskan faktor-faktor berdasarkan kepentingannya. Seterusnya, satu set data disediakan untuk membangunkan model menggunakan faktor-

faktor risiko ini dan data sejarah mengenai lebihan kos daripada projek petrokimia di Iran. Model ini, berdasarkan algoritma pokok keputusan daripada pembelajaran mesin, bertujuan untuk meramalkan sama ada lebihan kos akan rendah, sederhana, atau tinggi. Hasilnya ialah 13 peraturan yang digunakan oleh model ini, yang boleh membantu menganggarkan lebihan kos untuk projek-projek masa depan. Kajian ini menyumbang kepada pemahaman akademik mengenai ramalan lebihan kos dan menawarkan alat praktikal kepada profesional industri untuk mengurangkan risiko kewangan dalam pengurusan projek petrokimia.

RISK-BASED COST OVERRUN PREDICTION MODEL FOR PETROCHEMICAL PROJECTS

ABSTRACT

Cost overruns are a significant issue in the construction industry, particularly in petrochemical projects. Understanding the critical reasons behind cost overruns and their impact is challenging. While many studies have explored cost overruns in construction, focusing on their causes and implications, there's a noticeable gap in research that specifically targets identifying these causes in petrochemical projects. Additionally, there's a need for predictive models that can estimate the likelihood of cost overruns in these projects. This study aims to address this gap by identifying the factors that lead to cost overruns in Iran's petrochemical projects and developing a model to predict cost overrun levels. The study uses quantitative (based on numbers) and qualitative (based on observations) research methods to thoroughly investigate the factors influencing cost overruns and develop a predictive model for the severity of cost overruns in Iran's petrochemical projects. Data was collected through interviews and surveys. The survey was designed based on findings from literature reviews and initial interviews, leading to the identification of 30 risk factors. Data was collected from 99 participants using a survey that assessed the cause-and-effect relationship of risk factors to cost overruns in Iran's petrochemical projects. The study analysed the collected data using various quantitative methods, including Risk Importance Index Analysis. This helped prioritize the factors based on their importance. Then, a dataset was prepared to develop a model using these risk factors and historical data on cost overruns from Iran's petrochemical projects. This model, based on the decision tree algorithm from machine learning, aims to predict whether cost overrun will be low, moderate, or high. The result was 13 rules that this model uses, which could help estimate cost overruns for future

projects. This study contributes to the academic understanding of predicting cost overruns and offers a practical tool for industry professionals to reduce financial risks in managing petrochemical projects.

CHAPTER 1
INTRODUCTION

1.1 Introduction

The petrochemical industry is a crucial sector in Iran's economy, contributing significantly to its gross domestic product and employing a considerable proportion of the workforce (Ghazizade et al., 2021). However, petrochemical projects face cost overruns due to several factors, such as management, financial fluctuations in commodity prices, geopolitical tensions, regulatory hurdles, and technical challenges (Johari et al., 2019). Developing a reliable prediction model for cost overruns in petrochemical projects requires a comprehensive understanding of the factors influencing project costs and their interdependencies (Ghazal & Hammad, 2022). Data-driven approaches can be instrumental in constructing such models by incorporating historical project data, economic indicators, industry trends, and risk factors specific to the Iranian context (Liravinia et al., 2023). Machine learning techniques, including regression analysis, neural networks, and decision trees, offer powerful tools for analysing complex datasets and identifying patterns contributing to cost overruns.

1.2 Research Background

Cost overruns in civil projects, particularly in the oil, gas, and petrochemical (OGP) industry, have become an increasing and complex problem, with significant implications for governments, stakeholders, and the public. Flyvbjerg et al in (2003), have found that approximately 86% of projects experience cost overruns, with an average overrun of 28%. The data collected from over 250 large infrastructural projects across different countries and time periods demonstrate the consistent occurrence of cost overruns. Furthermore, the study by Tsegay Gebrehiwet and Hanbin Luo (2017) supports these findings, stating that construction projects often experience time overruns of 70% and cost overruns of 50%. Bentil et al. (2017) investigated cost overruns in Ghana, revealing a 75% overrun rate for public projects and 34% for private projects. Senoucia et al. (2016) explored cost overruns in the construction sector projects in Qatar, noting a 54% overrun rate.

In Iran, Heravi, and Mohammadian (2019) assessed project costs, categorizing them into three tiers: (1) Small, denoting projects valued at less than 160,000 USD, (2) Medium, encompassing projects valued between 160,000 and 480,000 USD, and (3) Large, representing projects valued over 480,000 USD. These thresholds were established considering typical value ranges for urban construction projects in Iran's construction industry. Their analysis revealed that among large projects, 43.8% experienced cost overruns exceeding 25%, while 56.2% encountered cost overruns of less than 25%. Additionally, according to recent research by Amini et al. (2023), construction projects in Iran are experiencing cost overruns exceeding 25%.

Assessment of factors contributing to cost overruns in civil projects is intricate and varied. In the recent study, Ibrahim et al. (2024) address the specific context of Somalia's construction industry, particularly focusing on the capital city of Mogadishu. Their study examines the primary causes of cost overruns in projects, emphasizing the need for a comprehensive understanding of materials, project management, contractor oversight, and unforeseen ground conditions to devise effective strategies for mitigation.

However, Omran et al. (2023) analyse the causes of time and cost overruns in Malaysian construction projects, highlighting issues such as lack of experience and errors in project documentation. Their study provides theoretical support and insights into cost overrun management in the construction industry, pinpointing top factors such as lack of project management experience, delays in information issuance, contractual claims, improvements to standard drawings, and errors in bills of quantities and quantity take-off. In addition, Tayyab et al. (2023) discovered a total of 70 elements contributing to cost overruns in high-rise construction projects in India. They identified the ten most significant reasons, including frequent change orders, construction delays, material price escalation, market inflation, rework, design modifications, erroneous project assessments, unanticipated ground conditions, inaccurate quantity take-off, and delayed payments by owners. Moreover, Sohu (2021) identifies critical risk factors of cost in the construction sector of Pakistan and ranks causes of cost overruns according to 33 common factors, including eleven financial challenges and troubles faced by contractors. Iranian projects are not exempt from cost overrun. Among the studies conducted in Iran, Derakhshan, and Teixeira (2017) evaluated the relative importance of the causes of cost overrun in the construction gas and oil industry. Their findings revealed that the main causes of cost overrun in this industry include inaccurate cost estimations, improper planning, frequent design changes, inadequate labour/skill availability, and inflation of costs of machinery, labour, raw material, and transportation prices. Abbasi (2020) identified eight main groups of risk factors for cost overrun in construction projects in Iran, including contractor, owner, design, procurement, equipment, consultant, labour, and miscellaneous. Key causes of cost overrun include financial difficulties, poor cash flow, delayed payments, inflation, material price increases, unrealistic schedules, and bidding system flaws.

Recent studies by Farzanegan and Batmanghelidj (2024) highlight the challenges faced by Iran's oil, gas, and petrochemical sectors due to economic sanctions. These sanctions, particularly those imposed after 2006, have significantly reduced Iran's oil export revenues, leading to currency depreciation, high inflation rates, and declining output growth (Laudati & Pesaran, 2023). Accurate cost estimation and prediction of cost overruns are crucial aspects of project management in the construction industry (Ashtari et al., 2022). Theingi Aung et al. (2023) delve into the potential of machine learning algorithms for cost overrun prediction, highlighting their superiority over traditional methods. In a similar vein, Ghazal and Hammad (2022) contribute to the advancement of cost overrun prediction models by utilizing data mining techniques. Their emphasis on simplicity and effectiveness through clustering, feature selection, and classification underscores the importance of practical and efficient approaches in addressing cost overrun challenges.

Eltoukhy and Nassar (2021) further enrich the discourse on cost overrun prediction by investigating its causes and effects. Employing linear regression and machine learning models, they not only predict overruns but also assess their severity. Additionally, Tajziyehchi et al. (2020) focus on identifying crucial features impacting cost overrun in construction projects. By employing dimensionality reduction techniques and machine learning algorithms, they enhance prediction accuracy, enabling stakeholders to better anticipate and mitigate cost overruns.

1.3 Problem Statement

The petrochemical industry faces numerous challenges, such as the need for efficient feedstock management, environmental concerns, fluctuating global demand, and volatile raw material prices. Issues like oil refining and petrochemical facilities corrosion, which can degrade equipment and harm the environment, require constant monitoring and mitigation efforts. Additionally, the industry's reliance on natural gas and oil as feedstocks, combined with regional competition and environmental regulations, pressures companies to innovate and adopt more sustainable technologies.

Economic factors, including project financing, investment cycles, and geopolitical stability, also significantly impact the viability and competitiveness of petrochemical projects. Furthermore, occupational hazards and health risks for workers in these facilities highlight the necessity for improved safety standards. The petrochemical industry must continuously adapt to evolving market dynamics, technological advancements, and regulatory frameworks to remain competitive.

Cost overruns in Iran's petrochemical projects are exacerbated by several risk factors, including political constraints, inadequate legislation, and high domestic inflation, which complicate project management and cost control (Johari et al., 2019). Petrochemical projects are intertwined with government policies and global oil prices, unlike other sectors, making them particularly vulnerable to financial mismanagement and external disruptions. The impact of these overruns extends beyond project delays, affecting the long-term sustainability and success of the entire industry.

Despite substantial investments in Iran's oil, gas, and petrochemical sectors totalling billions of dollars annually 78% of these projects experience cost overruns, with an average increase of over 25% from the initial budget (Esmaeili & Kashani, 2022). This trend is financially unsustainable and threatens the industry's global competitiveness by disrupting project timelines, straining financial resources, and diminishing stakeholder confidence (Khouzani & Soheilizadeh, 2022). These overruns have far-reaching consequences, impacting government revenues, investor trust, and the broader economic ecosystem.

Addressing the root causes of cost overruns in Iran's petrochemical projects requires thoroughly analysing the sector's risk factors and unique project challenges. These challenges include fluctuating raw material costs, political instability, regulatory changes, and the technical complexities of petrochemical production. While research has identified general factors contributing to cost overruns in construction, a significant gap exists in studying Iran's petrochemical industry (Abbasi et al., 2020; Amini et al., 2023). A sector-specific investigation is crucial to develop tailored mitigation strategies.

Understanding and mitigating these cost overruns is essential for maintaining the viability of Iran's petrochemical industry, which serves as a cornerstone of the national economy. Failure to address these issues could lead to wasted resources, delayed projects, and stunted industrial growth. Furthermore, these overruns place Iran at a competitive disadvantage as other countries invest in more efficient petrochemical projects. A comprehensive investigation into the factors driving cost overruns will enable Iran to improve project estimation accuracy, enhance construction management practices, and reduce financial risks.

Inaccurate cost estimations significantly contribute to overruns, as statistical analysis shows that estimates tend to be overly optimistic and biased, leading to flawed decision-making (Flyvbjerg & Bester, 2022). Traditional cost estimation methods are fraught with uncertainty, highlighting the need for improvements in predictive accuracy (Ghazal & Hammad, 2022). There is an increasing need for user-friendly machine learning tools to tackle this issue, which could improve cost overrun predictions and enhance project management. Implementing advanced technologies can mitigate risks, improve performance, and lead to more successful and sustainable projects (Liravinia et al., 2023; Majrouhi Sardroud et al., 2021).

Despite extensive research on cost overruns in construction, a critical gap remains in understanding these challenges within Iran's petrochemical industry. Much of the literature focuses on general construction and infrastructure projects, paying little attention to the unique complexities of petrochemical projects, which involve specialized processes, fluctuating global commodity prices, intricate supply chains, and regulatory challenges (Abbasi et al., 2020; Amini et al., 2023). Although cost estimation methods are well-studied, research on adapting or improving these methods for Iran's petrochemical projects particularly given their vulnerability to domestic and international economic fluctuations remains limited (Flyvbjerg & Bester, 2022; Ghazal & Hammad, 2022). Additionally, applying advanced predictive tools, such as machine learning and artificial intelligence, is sparse in the petrochemical sector despite these technologies being effective in other industries (Liravinia et al., 2023). Another gap is the insufficient analysis of local and global economic factors, including inflation, currency fluctuations, and trade sanctions, significantly affecting the financial outcomes of large-scale petrochemical projects in Iran. Addressing these gaps is essential for improving project management, reducing financial risks, and fostering long-term growth in Iran's critical petrochemical industry.

Addressing cost overruns in the petrochemical sector is vital for the industry's economic sustainability and the broader development of Iran's industrial infrastructure. The petrochemical sector is central to Iran's non-oil exports and industrial diversification strategy. If cost overruns persist, Iran's ability to meet domestic demand and compete internationally will be severely compromised. Given the petrochemical industry's significant economic and strategic importance, mitigating cost overruns must be a top priority to ensure future growth, attract foreign investment, and optimize national resources.

1.4 Research Questions

Identifying risk factors affecting cost overrun at petrochemical projects in Iran and developing a prediction model of cost overrun are the targets of this research. To achieve study objectives, the following research questions are formulated:

1. What are the significant risk factors influencing to the cost overrun in petrochemical projects in Iran?
2. What is the ranking of cost overrun risk factors in the petrochemical projects in Iran?
3. How can cost overrun be predicted accurately in petrochemical projects?

1.5 Research Objectives

The main aim of this study is to develop a prediction model of cost overrun based on the critical risk factors of cost overrun in petrochemical projects in Iran. To accomplish the aim, three objectives are introduced:

1. To identify the risk factors affecting the cost overrun, particularly in the petrochemical projects in Iran.
2. To rank the risk factors of cost overrun in the petrochemical projects in Iran.
3. To develop a prediction model of cost overrun in the petrochemical projects in Iran.

1.6 Scope of Study

This research, which values its participants' diverse perspectives and experiences, focuses on identifying and analysing the risk factors contributing to cost overruns in petrochemical projects in Iran, specifically focusing on the Mahshahr Special Economic Zone in Khuzestan province. The study aims to develop a predictive model for cost overruns in these projects. It begins with a comprehensive literature review to identify existing risk factors associated with cost overruns in construction projects worldwide. Then, primary data is collected through interviews and questionnaires involving participants with diverse professional backgrounds, roles, project involvement, and educational levels. These methods provide insights into the specific risk factors affecting petrochemical projects in the Mahshahr Special Economic Zone, Khuzestan. Participants include vital stakeholders directly involved in petrochemical projects, such as project managers, engineers, contractors, and government officials. The selection criteria ensure representation from the industry's public and private sectors, reflecting various levels of experience and expertise. This research offers a comprehensive understanding of the factors contributing to cost overruns in completed and ongoing petrochemical projects in Iran. Additionally, the study addresses the challenges faced by petrochemical projects within the Mahshahr Special Economic Zone and Khuzestan province.

1.7 Significance of the Study

This study's significance lies in its targeted exploration of the petrochemical industry in Iran, a sector that plays a vital role in the country's economic stability and growth. Understanding the risk factors contributing to cost overruns in this industry is essential for project managers and stakeholders. It will enable them to accurately estimate costs, minimize project failures, and improve the overall efficiency of project management. The significance of this study is reflected in its contribution to the knowledge and understanding of cost overruns in the petrochemical industry, specifically in Iran. Additionally, developing a predictive model will provide a practical tool for predicting cost overrun and decision-making. This predictive model can assist project managers in identifying and mitigating risks, optimizing resource allocation, and ensuring petrochemical project completion. The findings of this study will also have broader implications for the petrochemical industry globally, as the identified risk factors and predictive model can serve as a foundation for understanding and managing cost overruns in similar industries worldwide.

1.8 Thesis Structure

This thesis is structured into six chapters, each contributing to a comprehensive understanding of the research topic and its implications. The chapters are outlined as follows:

Chapter 1: Introduction: The chapter focuses on introduction of the research topic. It encompasses the research background, the research problem, research questions, Objectives of the research, significance of research, scope of the study, Research Methodology and Thesis Structure.

Chapter 2: Literature Review: The chapter vastly discusses the relevant literature review from previous writing research in line with the scope, such as cost overruns in construction projects and risk factors causing cost overruns. Moreover, it discusses previous research about prediction models of cost overruns and the accuracy of the performance of those models.

Chapter 3: Research Methodology: The chapter will focus on the research approach strategies and methodology employed in carrying out the research. This contains the research process and design, population and sampling techniques, and the data collection and analysis method.

Chapter 4: Data Analysis: This chapter provides the survey findings, identifies risk factors of cost overrun in the petrochemical projects in Iran, and presents a prediction model.

Chapter 5: Discussions and Findings: This chapter presents and discusses the findings obtained from the data analysis. By examining the results in detail, this chapter aims to provide insights into the research questions, objectives, and implications of the study. Throughout this chapter, the results of the data analysis will be presented and discussed clearly and concisely to shed light on the significance of the findings and their potential implications for future research and practice.

Chapter 6: Conclusions and recommendations: The conclusion chapter outlines the study's main findings and offers suggestions for future research. It summarizes what was discovered in the previous chapter concerning the study's goals. Every research has limitations, and this chapter discusses them and their impact on the study's results. Additionally, it highlights insights from international research and proposes ideas for future studies.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

This chapter presents a comprehensive literature review that offers insights into the global landscape of petrochemical projects, with a specific focus on Iran. Based on multiple previous studies, the review identifies critical risk factors that contribute to cost overruns in the construction industry, providing readers with a thorough understanding of the research area. Reviewing the prediction model of cost overruns outlines the various causes, effects, and potential solutions to this pervasive issue in construction projects.

2.2 Definition

2.2.1 Cost Overrun

A cost overrun occurs when the actual expenses of a project surpass the originally allocated budget, requiring the provision of additional funds. Also referred to as "budget overrun," "cost escalation," or "cost increase," this challenge is a significant hurdle for project managers as they strive to control rising costs. Cost escalation specifically pertains to the need for increased funding to finish a project beyond the initial financial plan, emphasizing the importance of proactive cost management (Flyvbjerg and Bester, 2022). Moreover, cost overrun reflects the gap between the initial budget estimate and the final cost at project completion, highlighting the need for careful budget planning and continuous oversight throughout the project lifecycle, particularly in the construction sector (Afzal et al., 2020).

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2.2.2 Prediction

Prediction is a proactive approach that helps identify potential risks and outcomes before they occur. In project management, particularly for large, high budget projects like those in the petrochemical sector, prediction allows for anticipating potential issues like cost overruns, material shortages, and equipment failures. Prediction involves using various methods to estimate future outcomes based on current and historical data. In the context of cost overruns, predicting the likelihood of a project exceeding its budget helps stakeholders to take proactive measures and mitigate financial risks (Theingi et al., 2023).

2.2.3 Key Sectors in the Oil and Gas Industry

The oil and gas industry are pivotal in shaping the global economy, providing the energy and raw materials that fuel modern industrial activities (Mohammed, 2023). This vast and multifaceted industry is responsible for oil and natural gas exploration, extraction, processing, transportation, and distribution. Its operations are spread across a comprehensive value chain, traditionally divided into three core sectors: upstream, midstream, and downstream (Craig & Quagliaroli, 2020). Each sector represents a crucial phase in bringing hydrocarbons from underground reservoirs to consumers worldwide, while petrochemical processes contribute significantly to the downstream sector's operations.

2.2.3(a) Upstream Sector: Exploration and Extraction

The upstream sector of the oil and gas industry contains the exploration, development, and extraction of oil and gas reserves beneath the Earth's surface. It includes geological surveys, seismic data collection, drilling, and the construction of wells to bring hydrocarbons to the surface. This phase is heavily dependent on advanced technologies and substantial capital investment. The upstream sector is marked by the risks and uncertainties of finding commercially viable oil and gas deposits, especially in remote or deepwater locations. The discovery and production of these resources are critical to the supply chain as they form the basis for the entire industry (Elijah et al., 2021).

2.2.3(b) Midstream Sector: Transportation and Storage

The midstream sector deals with the transportation, storage, and sometimes the initial processing of the extracted oil and gas. Once hydrocarbons are brought to the surface, they must be transported often over long distances from the production site to refineries or distribution networks. This is accomplished through an extensive network of pipelines, railways, trucks, and shipping vessels (Elijah et al., 2021). The midstream sector also manages storage facilities to ensure sufficient reserves to meet market demand. The midstream phase may also include processing natural gas to remove impurities such as water and sulfur, making it suitable for distribution. Efficient operations in the midstream sector are essential to providing a stable and reliable supply of natural hydrocarbons for further refinement and consumption (Kirima, 2022).

2.2.3(c) Downstream Sector: Refining, Petrochemicals, Distribution, and Sales

The downstream sector focuses on refining crude oil and processing natural gas into usable products, including fuels (gasoline, diesel, jet fuel), lubricants, and chemicals. This is where the raw hydrocarbons are transformed into finished goods that consumers and industries rely on daily (Tanaka and Bushuyev, 2021). The petrochemical industry is a critical part of the downstream sector, which produces a wide range of chemical products, such as plastics, synthetic rubber, and other industrial chemicals derived from petroleum and natural gas byproducts (Kirima, 2022).

2.3 Overview Petrochemical Industry Worldwide

The Americas, encompassing North, Central, and South America, have witnessed a significant surge in petrochemical projects over recent years (Han & Sun, 2023). These experiences are essential for economic diversification, technological innovation, and socio-economic development (Mara et al., 2023). The importance of petrochemical projects in the Americas cannot be overstated. They involve complex infrastructure and technological requirements and often transit vast geographical areas, necessitating refined logistical solutions and a substantial workforce (Dinariyana et al., 2021). In petrochemical projects in the American, risks come from multiple sources and can significantly impact project timelines and budgets (Rodhi et al., 2018). Strict environmental regulations play an essential role, making compliance a critical risk. Geopolitical tensions and trade restrictions can introduce uncertainties in the supply chain, affecting raw material availability and cost (Fiseha Mara et al., 2023). Market volatility, influenced by fluctuating global oil prices and regional economic stability, poses financial risks. Extreme weather events due to climate change present operational risks, threatening construction integrity and operational continuity (Setiadi & Dhewanto, 2022). Community acceptance and social license to operate are crucial, as local opposition can cause significant delays and increased costs. Risk management strategies are needed to address these challenges in the petrochemical industry in this region (Rivera-Basques et al., 2021).

The Middle East, a region with vast oil reserves, is pivotal in the global petrochemical industry. This region's abundance of petroleum and natural gas resources provides a competitive advantage for the production of petrochemicals (Dinariyana et al., 2021). Countries like Saudi Arabia, Iran, and Qatar have capitalized on this advantage and strategically invested in expanding their petrochemical capabilities. This expansion is part of a broader economic diversification strategy to reduce dependence on crude oil exports (Cetinkaya et al., 2018). Petrochemical projects in the Middle East face unique risks due to the region's geopolitical and economic landscape (Rodhi et al., 2018b). Political instability and regional conflicts can disrupt project execution while fluctuating global demand for oil and reliance on petroleum exports pose market risks (Alam et al., 2021). Supply chain disruptions, harsh climatic conditions, and water scarcity add further challenges (Al-Samhan et al., 2022). Regulatory risks, such as changes in environmental and labour laws, must be monitored to avoid delays and costly modifications (Akhtar, 2020).

The petrochemical industry in Europe is crucial for the region's economy, providing materials for the automotive, healthcare, electronics, and construction sectors (Van Wely, 2017). It creates jobs, drives technological innovation, and contributes significantly to the gross domestic product (Al Samhan et al., 2022). Moreover, the industry is critical in addressing climate change and resource scarcity by developing sustainable solutions. European companies are known for their focus on innovation, sustainability, and adherence to stringent environmental standards (Saygin & Gielen, 2021). They lead the adoption of advanced technologies and practices to meet regulatory requirements and public expectations for greener processes. Petrochemical projects in Europe face numerous risks related to environmental regulations, sustainable practices, and the global climate change agenda. Adhering to the European Union's environmental directives and the Emissions

Trading System increases project costs and complexity. Economic risks arise due to fluctuations in the Eurozone's financial markets and uncertainties as Brexit.

Technological innovation poses challenges of rapid obsolescence and the need for continuous investment. Potential risks to reputation are associated with the emphasis on using renewable energy sources (Midttun et al., 2022). In addition, the costs and timelines of projects can be affected by labour laws and the presence of an organized labour force. Therefore, European petrochemical initiatives require meticulous risk management, compliance strategies, stakeholder engagement, and resilience planning (Andrée & Hansson, 2023).

The petrochemical industry in Africa is still in its initial stages of development compared to other regions worldwide (Rajagopaul et al., 2020). However, promising signs indicate that the industry has significant potential for growth (Cs & Nc, 2016). The continent's abundant natural resources, such as oil and natural gas, are positioning it to become a key player in the petrochemical sector (Kuranchie et al., 2019). Petrochemical projects in Africa face various critical risks, including infrastructure deficits, political instability, financial constraints, environmental concerns, and technological adaptation. Inadequate transportation networks and energy supply issues present logistical challenges, while governance issues and fluctuating regulations can lead to project delays (Herman, 2023). Limited access to funding and currency uncertainty increases. financial risks. Water scarcity, biodiversity impact, and community relations add to environmental and social risks (Boughaba et al., 2014).

The Asia Pacific region, encompassing powerhouse economies like China and India and emerging players such as Malaysia, Singapore, Vietnam, and Indonesia, is experiencing a significant transformation in its petrochemical sector (Zhou Peng et al., 2023). This growth is propelled by increasing domestic demand and strategic investments aimed at capacity expansion and technological advancement (Zhang et al., 2019). The changing economic landscape in Asia presents considerable challenges to petrochemical projects. While there is a growing demand for petrochemical products, addressing complex logistical issues is essential (Azmi & Salleh, 2021). Regulatory differences among countries present significant challenges, as each nation has environmental and industrial policies affecting costs and operations (Du et al., 2018). Natural disasters such as typhoons, earthquakes, and floods threaten supply chains. The competitive labour market may also lead to labour shortages and increased costs (Makhanov et al., 2023). Political instability and varying bureaucratic efficiency can create unpredictability in project approvals and continuity (Dinariyana et al., 2021). Risks related to intellectual property, currency fluctuations, and technological advancements further complicate the management, financial, and strategic outlook (Barrault et al., 2012).

From the review of petrochemical projects worldwide, the researcher attempted to conclude the overarching themes and challenges that characterize the global landscape of the industry. This comprehensive analysis highlights the critical role of the petrochemical sector in driving economic diversification, technological innovation, and socio-economic development across different regions. Each region, from the Americas to the Asia Pacific, brings unique strengths while distinctive challenges, including environmental regulations, geopolitical tensions, market volatility, and infrastructure deficits. The synthesis of these projects underscores the industry's resilience and strategic importance, facing the complex interplay of economic, environmental, and geopolitical factors. Through this, the researcher aims to shed light on the challenges faced by Iran's petrochemical projects compared to global trends.

Construction projects in Iran, particularly in the petrochemical sector, frequently experience cost overruns, making this issue a critical challenge for the country's industrial and economic development (Derakhshanalavijeh & Teixeira, 2016). The petrochemical industry, which is vital to Iran's growth, plays a pivotal role in transforming the country's abundant oil and gas resources into value-added products. These projects are large-scale, complex, and require significant financial resources, often spanning various activities such as exploration, extraction, refining, and distribution (Ghazizade et al., 2021). Table 2.1 shows the significant petrochemical projects worldwide. It overviews major projects in the Americas, Asia, Europe, the Middle East, and Africa, highlighting key aspects such as costs and capacities.

Table 2.1 Largest Petrochemical Projects in the World

Region	**Project**	**Cost (in billion $)**	**Capacity**
Americas	Exxonmobil's Baytown Olefins Plant Expansion (United States)	2	1.5 million tons of ethylene/year
Americas	Chevron Phillips Chemical's Cedar Bayou Facility (United States)	6	1.5 million tons/year of ethylene
Americas	Petrobras' Comperj Complex (Brazil)	13	165,000 barrels per day refining capacity, significant petrochemical production
Americas	Braskem's Ethylene XXI Project (Mexico)	5.2	1 million tons of polyethylene/year

Americas	Sasol's Ethane Cracker and Derivatives Complex (United States)	12.9	1.5 million tons/year of ethylene
Americas	Formosa Plastics' Point Comfort Facility (United States)	5	1.2 million tons/year of ethylene
Americas	Ecopetrol's Reficar Refinery Expansion (Colombia)	8	165,000 barrels per day
Americas	Odebrecht and Braskem's Appalachian Petrochemical Complex (United States)	6	1.5 million tons/year of polyethylene
Middle East	Saudi Aramco Petrochemical Projects (Saudi Arabia)	25	Over 5 million tons/year of petrochemicals
Middle East	SABIC Petrochemical Complex (Saudi Arabia)	20	10 million tons/year of petrochemical products
Middle East	Sadara Chemical Company (Saudi Arabia)	20	3 million tons/year
Middle East	Ras Laffan Olefins Complex (Qatar)	6	1.6 million tons/year of ethylene
Middle East	Borouge Petrochemical Complex (UAE)	8	4.5 million tons/year of polyolefins
Middle East	Al-Zour Refinery (Kuwait)	16	615,000 barrels per day
Asia	Zhejiang Petrochemical's 40-Million-Ton Refinery Integration Project (China)	30	40 million tons/year
Asia	Hengli Petrochemical Complex (China)	20	20 million tons/year
Asia	RAPID Project, Malaysia	27	7 million tons/year

Asia	Sinopec And ExxonMobil's Guangdong Integrated Petrochemical Complex (China)	10	1.2 million tons/year
Asia	Singapore ExxonMobil's Ethylene Expansion Project (Singapore)	8	2 million tons/year of ethylene
Asia	Reliance Industries' Jamnagar Refinery (India)	20	1.2 million barrels per day
Europe	BASF's Verbund Site (Germany)	10	14.5 million tons/year of various chemicals
Europe	INEOS Project ONE (Belgium)	14	1.25 million tons/year of ethylene
Europe	Shell's Ethylene Cracker Complex in Moerdijk (Netherlands)	3	0.9 million tons/year of ethylene
Europe	Neste's Renewable Products Refinery (Netherlands)	1.5	1 million tons/year of renewable diesel
Africa	Dangote Refinery and Petrochemical Complex (Nigeria)	19	650,000 barrels per day
Africa	Sasol's Secunda Complex (South Africa)	8	7.5 million tons/year (coal-to-liquid)
Africa	Egyptian Ethylene and Derivatives Company (Ethydco) (Egypt)	1.9	460,000 tons/year of ethylene
Africa	Sonatrach's Skikda Refinery (Algeria)	7	335,000 barrels per day

Source: S&P Global Commodity Insights (2022).

2.3.1 Petrochemical Production Capacity

In the global petrochemical industry, Iran has been working to position as a significant player. It is among the top ten countries in terms of petrochemical production capacity. Figure 2.1 shows the petrochemical capacity additions worldwide between 2019 and 2030, broken down by country (Statista, Petrochemical Capacity, 2023). The data measured in million metric tons annually (MMT/yr.).

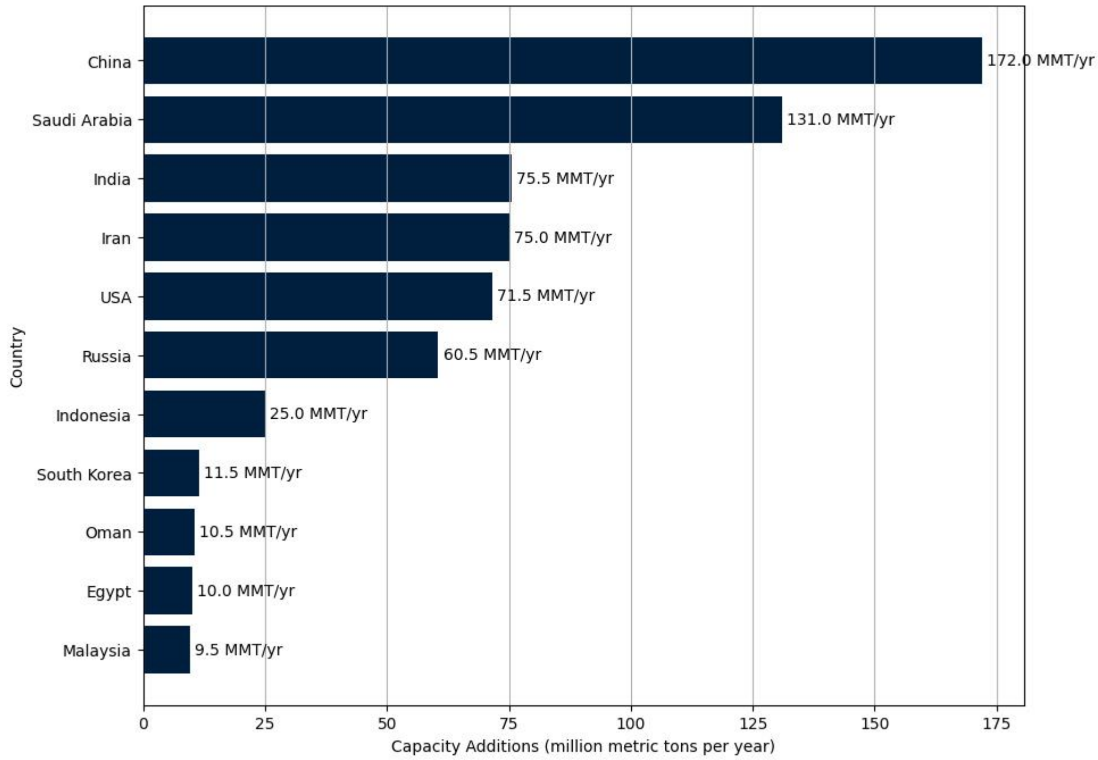

Figure 2.1 Petrochemical capacity 2019-2030.

Source: Adapted from Statista, Petrochemical Capacity, 2023).

The bar chart illustrates the capacity additions of various countries in million metric tons per year (MMT/yr). China leads the global expansion with the largest capacity addition of 172.0 MMT/yr, indicating its dominant role in industrial or resource growth. Following China, Saudi Arabia holds the second position with a substantial addition of 131.0 MMT/yr. India and Iran both exhibit significant expansions, with India at 75.5 MMT/yr and Iran closely following at 75.0 MMT/yr.

The United States also contributes notably with 71.5 MMT/yr in capacity additions, positioning it just behind India and Iran. Russia, with 60.5 MMT/yr, remains another major player in this landscape. Indonesia adds 25.0 MMT/yr, reflecting a moderate capacity increase. Meanwhile, South Korea and Oman contribute 11.5 MMT/yr and 10.5 MMT/yr, respectively, showing smaller yet relevant growth. Finally, Egypt and Malaysia round out the chart with 10.0 MMT/yr and 9.5 MMT/yr in capacity additions, placing them at the lower end of this list. Overall, China and Saudi Arabia are the clear leaders in terms of capacity expansion, while Malaysia contributes the smallest amount among the countries listed.

2.4 Overview Petrochemical Industry in Iran

The petrochemical industry in Iran has a rich history dating back to the late 1950s. With a large domestic market and abundant hydrocarbon reserves, the sector experienced rapid growth and expansion (National Iranian South Oil Company, 2006). The Fertilizer Authority was established in 1958, followed by the National Petrochemical Company (NPC) in 1964 to plan for industry development (National Petrochemical Company, 2011). The Iran-Iraq war had a severe impact on the economy, including the petrochemical sector, causing a halt in investments and significant damage to facilities. However, the Iranian Petrochemical Company, NPC, has experienced significant changes over the past decade. NPC has shifted from being a developer to a regulator and policymaker in line with the country's constitution, which promotes privatization. NPC divested all its process plants and service facilities while still retaining responsibility for supervising and owning stocks of private petrochemical companies. This new role positions NPC as a macro planner within the Ministry of Oil and Gas (INPC, 2014).

2.4.1 Effects of Sanctions on the Petrochemical Industry in Iran

Before the 2012 sanctions, Iran had attracted several international oil companies (IOCs) due to its vast oil and gas reserves. The companies, including (CNPC, ENI, Total Fina Elf, and Royal Dutch Shell) collaborated with the National Iranian Oil Company (NIOC) to develop Iran's petrochemical resources (Iran’s Energy Policy, 2016). Their activities involved exploration, drilling, development of oil and gas extraction facilities, and infrastructure setup for transportation. Some companies also operated refineries and gas processing plants for domestic and export purposes. These IOCs brought technology, expertise, and capital for accessing and maximizing Iran's oil and gas fields. However, the post-sanction period saw many companies withdraw, significantly impacting Iran's oil and gas, particularly the petrochemical industry (Farashah et al., 2020). The international oil companies’ activities in Iran before the 2012 sanctions, as Figure 2.2 illustrates.